THE EFFECT OF FREQUENCY ON THE BREAK DOWN VOLTAGE OF LIGHTNING ARRESTERS

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ARMOUR INSTITUTE OF TECHNOLOGY

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The effect of Frequency on the break down Voltage of Lighting Arresters.

A THESIS

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PART I.

INTRODUCTION.

Development.

Principles of Operation.

Characteristics.

INTRODUCTION.

Electrical energy and its transmission has afforded problems ever since it became of importance in a commercial sense. Especially at the present time, in the days of expensive central station machinery and long distance transmission some problems are forcibly marked for solution. The term forcibly may be taken literally without any error. The devastating force of uncontrolled electricity is as intense as that of fire or water. The protection of machinery and transmission lines, from this source of trouble, has not been one of the smallest problems presented. The effects are most destructive in the central station and substations, but as the lines are usually the point of attack the former are best protected by protecting the latter. The importance of this protection is becoming greater with the wider application of electricity and the

conditions which the producer must agree to. For instance, if a company is supplying a large factory or an electric railway, the company must guarantee continuous power, with a heavy penalty for failure. This is especially the case where the electricity is used in mines and where human lives depend on the continuity of the power supplied.

Protection against lightning is one of the greatest, of the unsolved, present day problems. Lightning phenomena must be studied as a preliminary to a successful attempt at lightning protection. While considering the subject of lightning protection it might be well to be sure the term lightning is properly understood. Steinmetz gives the following definition; "Lightning in its broader sense comprises all the effects of voltages differing from and usually higher than the normal operating voltage of a system".

This phenomena may be devided into two general classes, surging and explosive. The first is usually produced by the apparatus used in generating or utilizing the electrical energy, while the latter is due to direct stroke. Though the explosive effect is the more destructive, it is the least common, and also the harder to properly contend with. The surging effects are more common, especially with alternating current machinery. They have also been considered more in the devices which have been put on the market for the purpose of offering lightning protection.

The production of protection from lightning had its inception as early as 1844 when Morse built his first telegraph line and the development has kept pace with the application. So large is the field and so rapid has been the development

that all the knowlege acquired has been somewhat superficial. It is now time that more careful and accurate knowlege should be attained than was possible in the age of rapid development. There are several problems which especially commend themselves for attention. Among these are problems pertaining to the resistance and the freedom of discharge, the method of a fuse arrester which will not stop synchronous machinery, the effect of variation of working conditions on an arrester, etc. It is only with additional knowlege on these and allied subjects that the adjustment of lightning protectors will become more than a rough approximation.

With the idea, that a little accurate knowlege is more valuable than more extensive and less reliable information, as a working basis, it was deter-

mined to make one step into the unknown. This step was the determination of the relation between the breakdown point and the frequency of the breakdown voltage. The following data was obtained with the above object in view. The result of the test is given in the succeeding chapters of this article, also graphically in the accompanying sketches and curves.

PART II.

ARRESTERS TESTED.

Description.

Advantages.

Faults.

ARRESTERS TESTED.

The basis of all lightning arresters seems to have been an air gap with means of breaking any arc which might form due to breakdown. The most recent developments of this type of arrester has resulted in the multi-gap arrester. This arrester consists of a number of series gaps between cylinders of non-arcing material. In further developments some of the gaps are shunted by non inductive resistance such as carbon pencils. There are a number of these shunts, each of which shunts a different number of gaps. This makes the arrester more flexible in regard to the size and the potential of the discharge. In some cases an additional resistance is placed between the gaps and ground. The theory of the action of this type of arrester is as follows; The resistance is so adjusted as to be proof against line potential. A breakdown occurs through the shunt resistance

and gaps and through the series resistance. When the electro-motive force, which caused the break-down, has passed, the strength of the current is so reduced by the non-inductive resistance that the arcs are extinguished. The leakage discharge takes place through the shunt resistance.

Owing to the wide and successful application of the type of arrester described in the preceeding paragraph, it was deemed advisable to begin the tests on the arrester of this type as manufactured by the General Electric Co., Another feature which recomended this arrester was its simplicity. The arrester on which this test was carried out is shown in Fig. 1. It consists of a porcelain base which supports three connections, two for line and one to ground. In series between the line and ground are two gaps and a carbon pencil. This arrester was a

low voltage type used on 3000 to 4000 volt lines. The line connections are at the top of the porcelain base. A raised portion of the base forms an insulating barrier between the two resistances. The screws by which the arrester is supported are counter sunk in this barrier. The whole forms, a very simple, compact and servicable arrester. On this arrester most of the available time was expended, and the results justified such expenditure. One other type was considered. However owing to the lack of time the quantity of data secured was not such as to justify any assertion as to the relation sought. This arrester, the Wurtz non-arcing, is shown in Fig. 2. It was a low voltage arrester. The gpas are formed by knurled metalic

cylinders supported on a marble base. The extensive discharge area is relied upon to prevent arcing. The line connections provided are a little more complicated than in the General Electric Company's arrester. The construction makes this arrester more expensive, and on that account, more limited as regards application. The cylinders are composed of an alloy which is not easily vaporized. This also tends to prevent arcing.

PART III.

METHOD OF TEST.

Apparatus.

Operation.

METHOD OF TESTING.

No small part of the time that could be contributed to this work was expended in the design and construction of the purely mechanical features connected with the test. The assembly of the apparatus is shown in Fig. 3. With the potential at which the tests were carried out it would not have been necessary to employ quite as much care in the design of the buses and the high tension connections, but it was deemed advisable to provide for future contingensies in regard to voltage.

The low tension or secondary electromotive force was supplied by a Westinghouse alternator. The same machine being used in each run. The power was generated single phase. The frequency was controlled by means of rheostats in the motor field. Owing to the effect of

the change of frequency on the generated voltage it was only possible to obtain the break down point at a given frequency by varying the voltage instead of determining both this and the reverse. The frequencies used were limited to the range of a frequency meter. It was first tried to use two meters and in this way extend the range. But as it was found this introduced an error it was thought the results would be more reliable if the only errors were constant ones introduced by the instruments. As the result sought was purely comparative and not quantitative constant errors would not cause trouble. The frequency meter was connected to the secondary or low potential side of the line by means of a small transformer with a ratio of transformation of 1/10. The frequency meter being in the primary circuit.

The voltage control was first attempted by means of field rheostats. It was found impossible to reduce the secondary voltage enough by this means. Resort was then had to the resistance of lamps. Several sizes of lamps being used in a special rack which provided for a combination of series and parallel resistance.

The primary circuit consisted of the primary of the static transformer with a ratio of transformation of 720 to 1. This winding was connected to the terminals of a needle gap and to the high potential buses. The buses consisted of large iron wires supported on high voltage insulators. Each bus was provided with a sliding contact and connector to facilitate connection being made to the arrester under test. All the high tension wiring was carried on a structure of pine.

The wires being carried on high tension insulators supported on pins set in the structure. The whole high tension side was constructed with 18" as the minimum clearance. Fig. 4 is a wiring diagram of the apparatus. The break down voltage was measured by means of the air gap between two needle points. Fig. 5 shows a characteristic discharge. The gauge shown in Fig. 6 was constructed to facilitate the adjustment and measurement of the air gap between the needle points and increase the accuracy of the measurements of the length of the air gap. The break down voltage was taken as the voltage which would cause a spark across the arrester gap and the needle gap in parallel. The needles being moved out by means of the screw on the guage until the aparking was wholly across the arrester. Then the needle points were

slowly brought together till sparking between them would occur. Fig. 7 is a photograph of a characteristic discharge across the gap between the needle points. The length of the gap was measured in sixty-fourths of an inch and reduced to volts from a calibration curve. A copy of this curve reduced is given in Fig. 9. The data for this curve was obtained from the A. I. E. E. rules of standardization. The data was taken in two different manners. At first several readings of voltage were made at one frequency. Changes in field resistance being made between such readings. The better results however were obtained by running through from minimum to maximum frequency and the reverse and taking one voltage reading at each point. The break down voltage was the surge voltage caused by suddenly closing a switch in the primary circuit. It was

thought that this surge voltage would most likely approach actual conditions than a steady voltage. The other voltage was tried and several conditions effecting the results were discovered. With the primary circuit closed it was noted that a much higher steady voltage was required than when the breakage was caused by a suddenly applied voltage. Again the presence of various objects in the field was noted to have effects on the discharge point. For instance if the operator stood near the arrester gap and a discharge took place across that gap and not across the needle gap the effect could be reversed by a change of position. Then if there was any vibration produced such as the passing of a train or the running of the permutator, discharges took place at lower voltage than was the case where the atmosphere and apparatus were in a state of rest. These

effects were not noticable when the other method was used. A slight vibration in closing the switch such as that caused by allowing the switch to fall shut was found more effective in inducing a spark than closing it by a steady pressure.

The data as presented comprises only the most consistent of the entire amount taken. The data taken in order to get the proper manner of operating and before the experimental work was entirely familiar was dispensed with on account of its lack of consistency. Though so far as it was considered it showed a tendancy toward the same result as given by the later data. The tests were carried out with connections from line to ground connecting points at first, but it was found that better results in regard to the break down point could be arrived at with a higher voltage. The later data was accordingly

taken from line to line or at double the arrester capacity.

The work done with the Wurtz arrester, as before stated, was not of sufficient extent to warrant any detailed consideration of the result. The experimental work had to be discontinued owing to unforeseen and unavoidable circumstances, when just begun. Fig. 8 shows a characteristic discharge of the arrester.

PART IV.

RESULTS OF TEST.

Explanation of

Curves and Data.

Conclusion.

RESULTS OF TEST.

This experimental work was carried out in the hope of obtaining sufficient data, upon which to base an equation giving the relation between the breakdown voltage of a lightning arrester and the frequency of the line current. The following sketches and curves are intended to convey graphically the results of this experimental work. The contents of this chapter are partly in explanation of, and partly in addition to these. Figure 9 is a copy of the curve used in obtaining the voltage values from the lenght of the spark. The original was drawn to a much larger scale , and afforded much more accuracy in estimating the values. The data obtained at each run was kept separately and was obtained as

follows. Data #1 is the average of ten readings at each frequency. At the time this was taken it was not possible to obtain a frequency over sixty-five cycles. The buses were connected to the line and ground terminalsand the required or breakdown voltage was between six and nine killovolts. Before this set of data was obtained a good many runs had been made, some cause of trouble discovered in each, and steps taken to eliminate such trouble in succeding runs. This data was finally obtained and recorded for the sake of comparisson. At this time it was found that a higher voltage could be controlled more readily, by the alternator field adjustments, hence the breakdown voltage from line to line or double that from line to ground was used. The data on sheet #2 was taken under these conditions, but on a rainy day, which accounts for the fact that the voltages are lower than in the

records presented on the following sheets. The voltages in this case varying from twelve to thirteen killovolts, while on bright, dry days thevoltages ranged from twelve to fourteen killovolts. The run one way of the range of the frequency meter occupied a day when several runs were made at each frequency, and owing to the variable weather conditions it was not possible to carry out the whole experiment under the same conditions. To overcome this difficulty a change of method of making the runs and obtaining the data was determined upon. The remaining data was obtained by finding one breakdown voltage at each frequency. As tjis occupied so much less time, it was possible to take readings , both with ascending and descending readings, throughout the range of the meter, and still have the experimental conditions constant. The

data shows the direction of change when read from top to bottom. The curves also give the direction as well as the values. Data #3 is ascending and #4 is the corresponding descending data, also #6 and #7, #8 and #9 are sheets of converse data. The composit curve was made by tracing all the other curves on one sheet, #4, #7 and #9 being reversed. It is seen from this sheet that there is a common point for all of the curves at about 115 alternations, also that there is one for several of of the curves at 85 alternations, or at a distance of 15 cycles. This would seem to indicate the effect of the third and fifth harmonics. As a suggestion, it might be profitable, if some means for readily reading the frequency could be obtained, to collect data covering a greater range of frequency, to determin just what this effect is. With curves covering a greater range it would

be possible to judge by their common points. With the results of this work as a foundation, and the mechanical work in its present state of construction, it would be possible to increase the scope of the work quite materially, with the expenditure of the same amount of time as was required for the work so far accomplished.

The air gap gauge was designed and constructed by the authors. It will be found a very useful adjunct in this character of work, as it reduces the errors of measurement and also reduces the time required in making adjustments. The gauge is intended for gaps of two inches and less. Though by means of reerence points, on the nedle bars, gaps of any length may be measured. The gauge is shown in Fig. 6. This print is not very clear, the sharpness of outline being sacrificed to increase the size.

There are so many possibilities connected with work of this kind, that a great deal of time would be required to experimentally prove any theory. The arrangement of the apparatus introduces elements of uncertanty that can only be discovered by obtaining consistent data under varying conditions. For instance, it is possible that the magnetic and static fields exercise some effect on the results. This could be determined by taking data with such variation, of the arrangement of the apparatus, as would eliminate one or more possible effects at each arrangement. In this way the presence and magnitude of such effects could be judged from a comparison of the different sets of data. Whether the possible results would justify an expenditure of time, such as this extended experimental work woud require, is a matter open to discussion. There are points raised for

Experiment and new subjects for reference reading at every advance. With more data, and the attending increase in familiarity with the component parts of the results, more definite statements could be made.

Steinmetz gives a discussion of harmonic current waves on pages 172-176 of his book on Alternating Current Phenomena. According to him, alternating current waves can be divided into two components, the sinusoidal and the wattless non-sinusoidal components. He states that an air gap will increase the first compoment, except under conditions of self induction. This is treated under the magnetic effects of alternating currents. Whether it has anything to do with the shape of the curves, offered in this work, can not be decided at present. However it is highly probable that the results are affected somewhat by this action. As

before stated, it would be necessary to determin this by the elimination process of experiment.

It is safe to state that the relation between the breakdown voltage and the frequency is a sinusoidal one, distorted by the super-position of the higher harmonics. The curves obtained warrant this statement. The varying frequency causes a variation of the wave form owing to the introduction of harmonics of different degree. An equation to give this relation would probably be a logarithmic one, at any rate it would be very complicated and could only be formulated with the aid of additional data and reference reading.

The work accomplished was carried out with every regard to detail and accuracy. An attempt being made at every step to account for discrepancies and

PART V.

RESULTS OF TEST.

(GRAPHICAL)

Data.

Curves.

Diagrams.

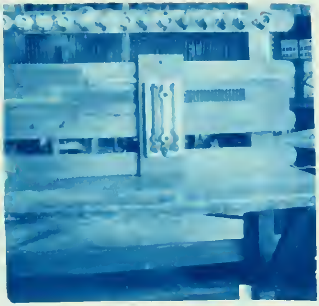

Fig. 1.

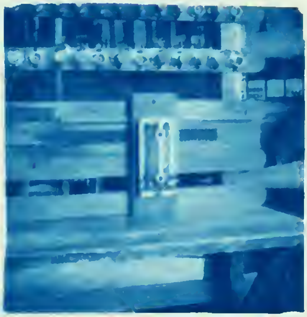

Fig 15.

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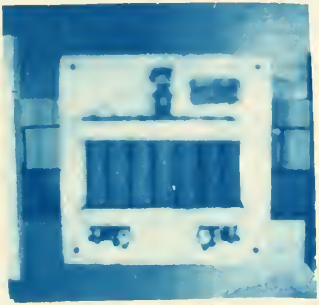

Fig. 2.

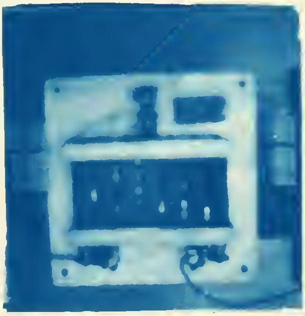

Fig. 8.

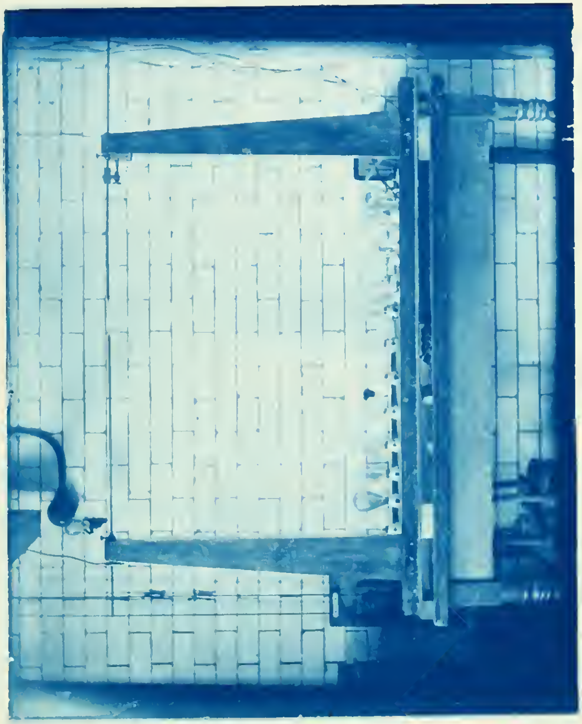

Fig. 3.

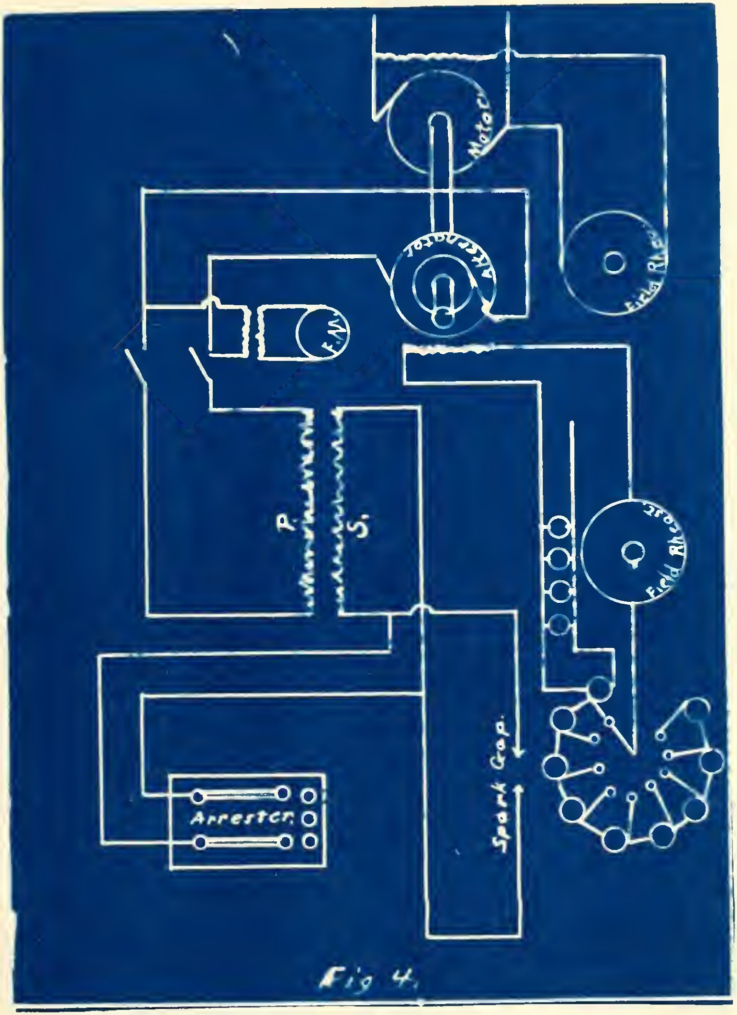
Motor
Alternator
Field Rheo.
F.W.
P.
S.
Field Rheostat
Arrester
Spark Gap.

Fig 4.

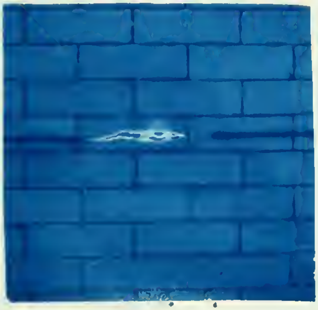

Fig. 6.

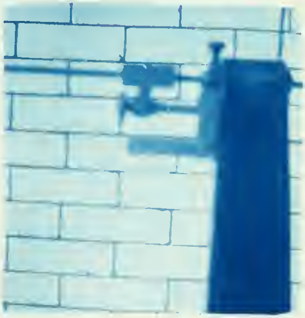

Fig. 7.

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Calibration Data.

Inch.	K.V.	Inch.	K.V.
.25	6.	.406	10.8
.266	6.65	.422	11.2
.281	7.4	.438	11.5
.297	7.6	.453	11.9
.313	8.2	.469	12.4
.328	8.8	.484	12.8
.344	9.15	.50	12.95
.360	9.6	.516	13.2
.375	10.0	.531	13.55
.391	10.4	.547	13.8

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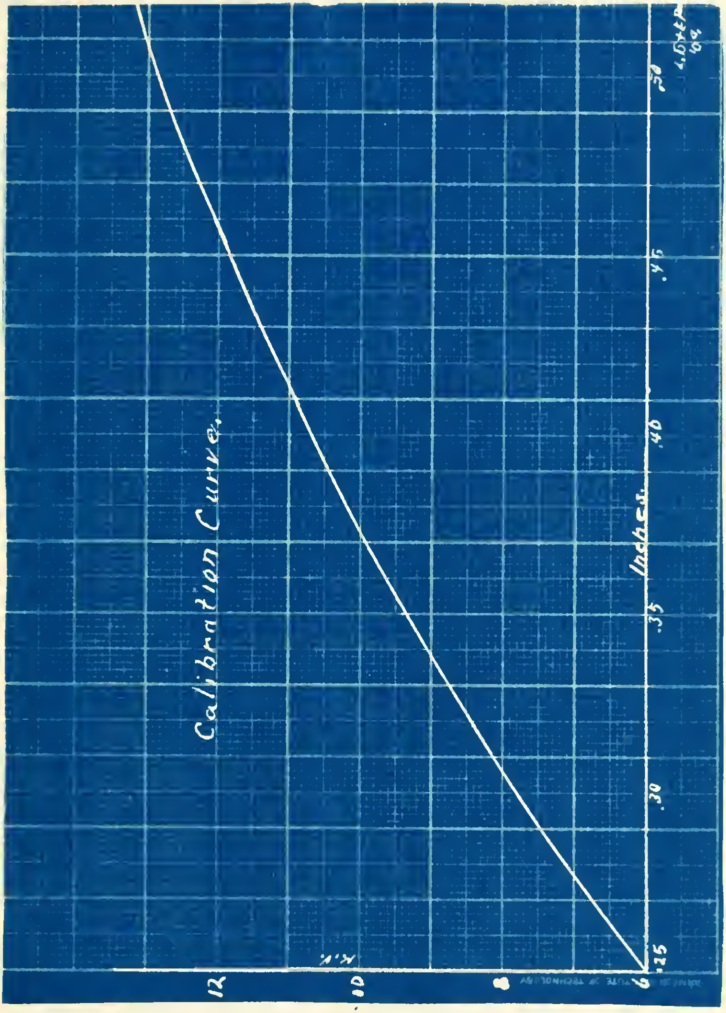
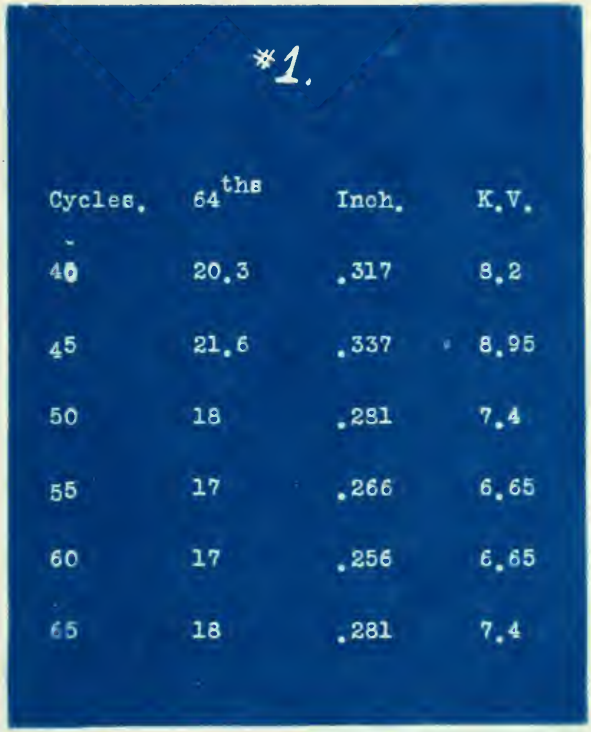


Fig. 9.



*1.

Cycles.	64^{ths}	Inch.	K.V.
40	20.3	.317	8.2
45	21.6	.337	8.95
50	18	.281	7.4
55	17	.266	6.65
60	17	.256	6.65
65	18	.281	7.4

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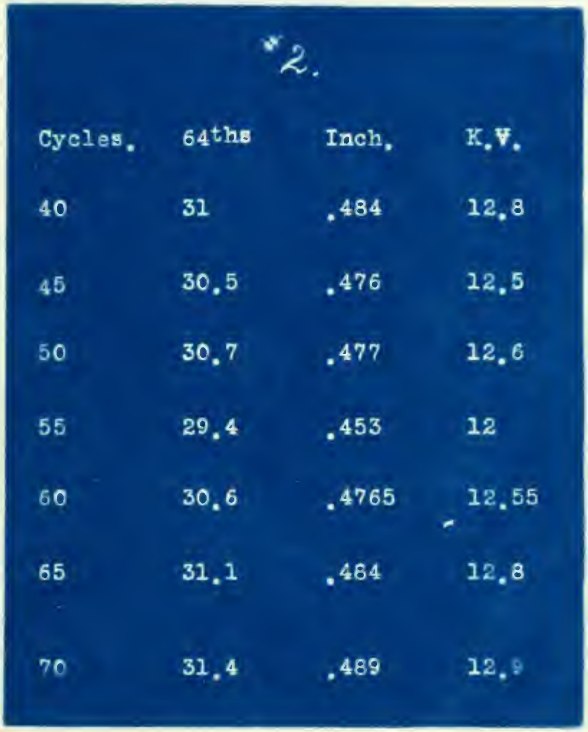

#2.

Cycles.	64ths	Inch.	K.V.
40	31	.484	12.8
45	30.5	.476	12.5
50	30.7	.477	12.6
55	29.4	.453	12
60	30.6	.4765	12.55
65	31.1	.484	12.8
70	31.4	.489	12.9

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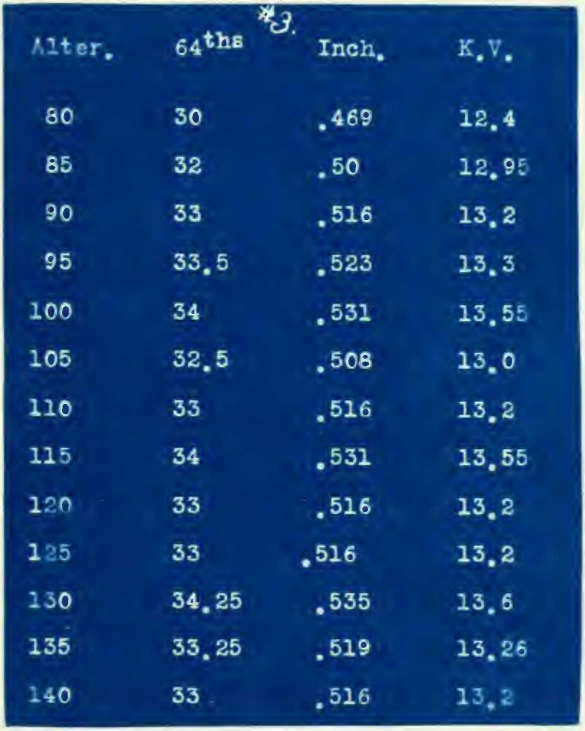

#3.

Alter.	64^{ths}	Inch.	K.V.
80	30	.469	12.4
85	32	.50	12.95
90	33	.516	13.2
95	33.5	.523	13.3
100	34	.531	13.55
105	32.5	.508	13.0
110	33	.516	13.2
115	34	.531	13.55
120	33	.516	13.2
125	33	.516	13.2
130	34.25	.535	13.6
135	33.25	.519	13.26
140	33	.516	13.2

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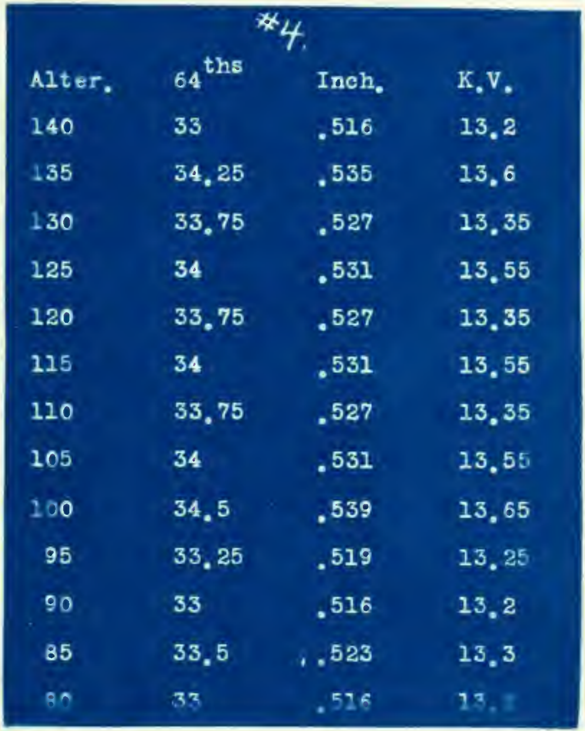

#4.

Alter.	64^{ths}	Inch.	K.V.
140	33	.516	13.2
135	34.25	.535	13.6
130	33.75	.527	13.35
125	34	.531	13.55
120	33.75	.527	13.35
115	34	.531	13.55
110	33.75	.527	13.35
105	34	.531	13.55
100	34.5	.539	13.65
95	33.25	.519	13.25
90	33	.516	13.2
85	33.5	.523	13.3
80	33	.516	13.2

[illegible]
[illegible]
[illegible]

Alter.	64ths	Inch.	K.V.
80	31.5	.489	12.5
85	32.75	.512	13.1
90	33.	.516	13.2
95	33.25	.519	13.26
100	34.25	.535	13.6
105	33.25	.519	13.26
110	33.25	.519	13.26
115	34.	.531	13.55
120	33.25	.519	13.26
125	33.5	.523	13.3
130	34.	.531	13.55
135	33.75	.527	13.35
140	33.	.516	13.2

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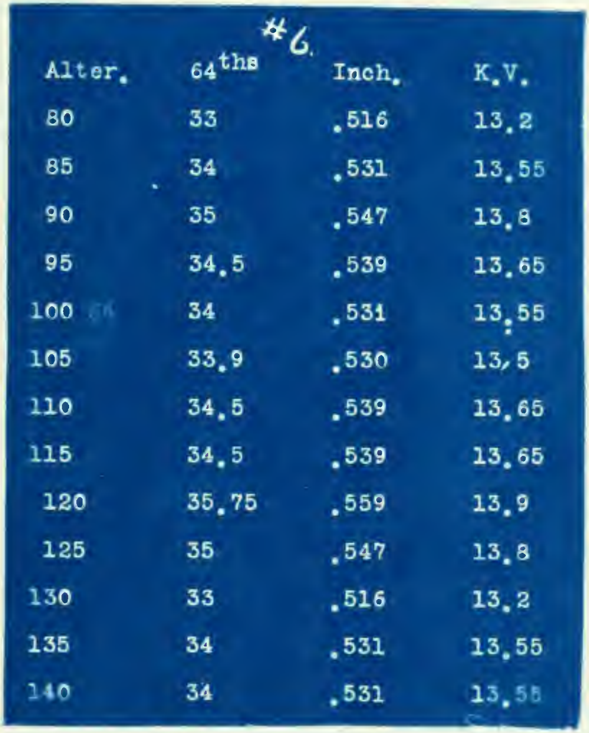

#6

Alter.	64$^{\text{ths}}$	Inch.	K.V.
80	33	.516	13.2
85	34	.531	13.55
90	35	.547	13.8
95	34.5	.539	13.65
100	34	.531	13.55
105	33.9	.530	13,5
110	34.5	.539	13.65
115	34.5	.539	13.65
120	35.75	.559	13.9
125	35	.547	13.8
130	33	.516	13.2
135	34	.531	13.55
140	34	.531	13.55

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#7

Alter.	64ths	Inch.	K.V.
140	34	.531	13.55
135	33	.516	13.2
130	34	.531	13.55
125	34.5	.539	13.65
120	35	.547	13.8
115	34.25	.535	13.6
110	34	.531	13.55
105	34	.531	13.55
100	34.5	.539	13.65
95	34.75	.543	13.75
90	34.5	.539	13.65
85	33.8	.528	13.5
80	34	.531	13.55

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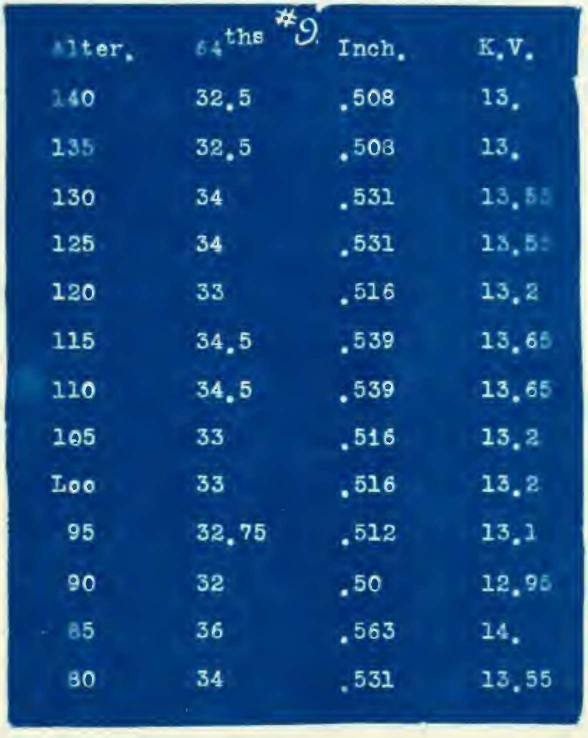
*8.

Alter.	64ths	Inch.	K.V.
80	31	.484	12.8
85	34	.531	13.55
90	34.5	.539	13.65
95	34	.531	13.55
100	34.5	.539	13.65
105	34.75	.543	13.75
110	36	.563	14.
115	34.25	.535	13.6
120	33	.516	13.2
125	34	.531	13.55
130	32	.50	12.95
135	32.75	.512	13.1
140	33	.516	13.2



#9

Alter.	64^{ths}	Inch.	K.V.
140	32.5	.508	13.
135	32.5	.508	13.
130	34	.531	13.55
125	34	.531	13.55
120	33	.516	13.2
115	34.5	.539	13.65
110	34.5	.539	13.65
105	33	.516	13.2
Loo	33	.516	13.2
95	32.75	.512	13.1
90	32	.50	12.95
85	36	.563	14.
80	34	.531	13.55

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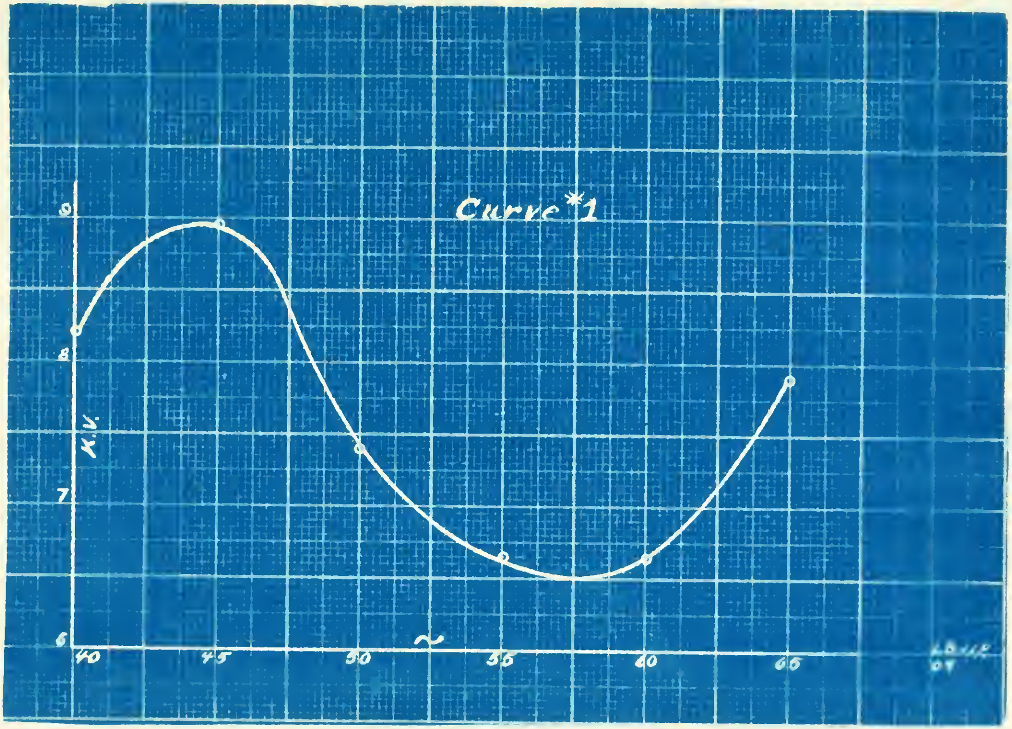
Curve *1
9
8
7
6
K.V.
40
45
50
55
60
65
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AGASSIZ
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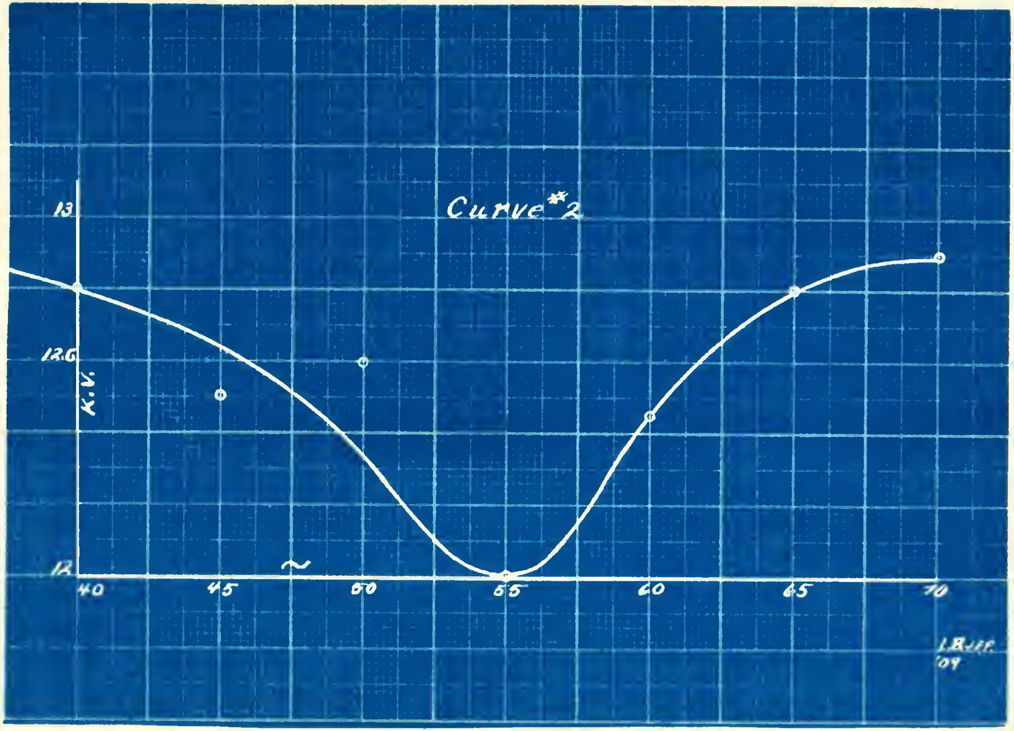
LIBRARY

Curve #2
13
12.6
12
K.V.
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40
45
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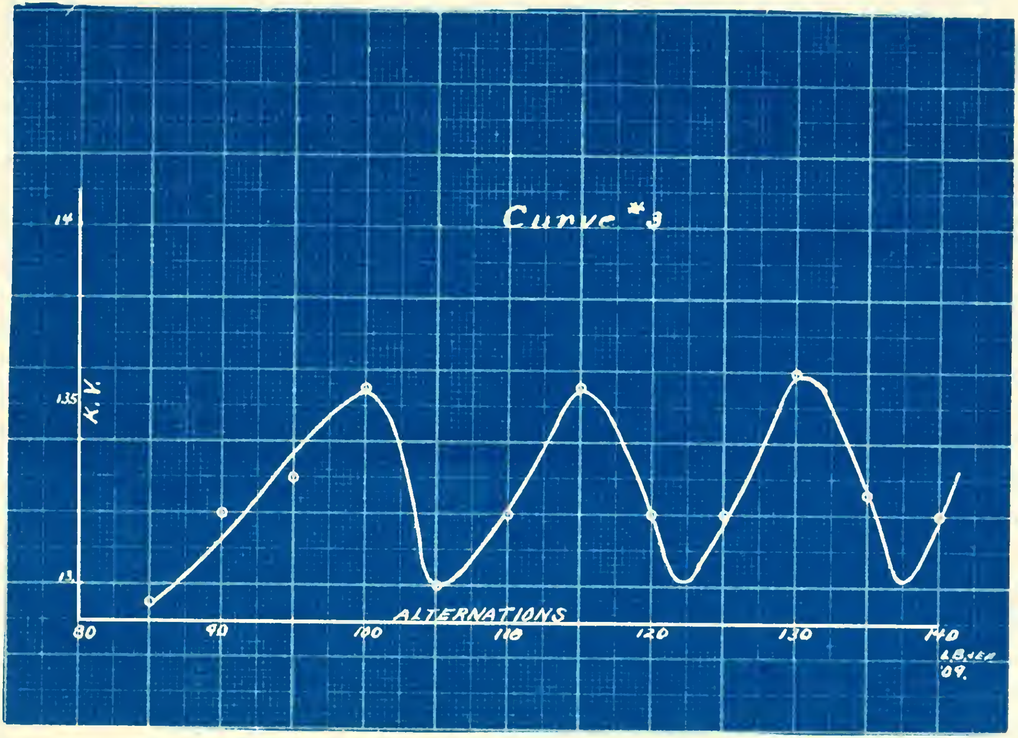
L.B.J.F.
'09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135
13
80
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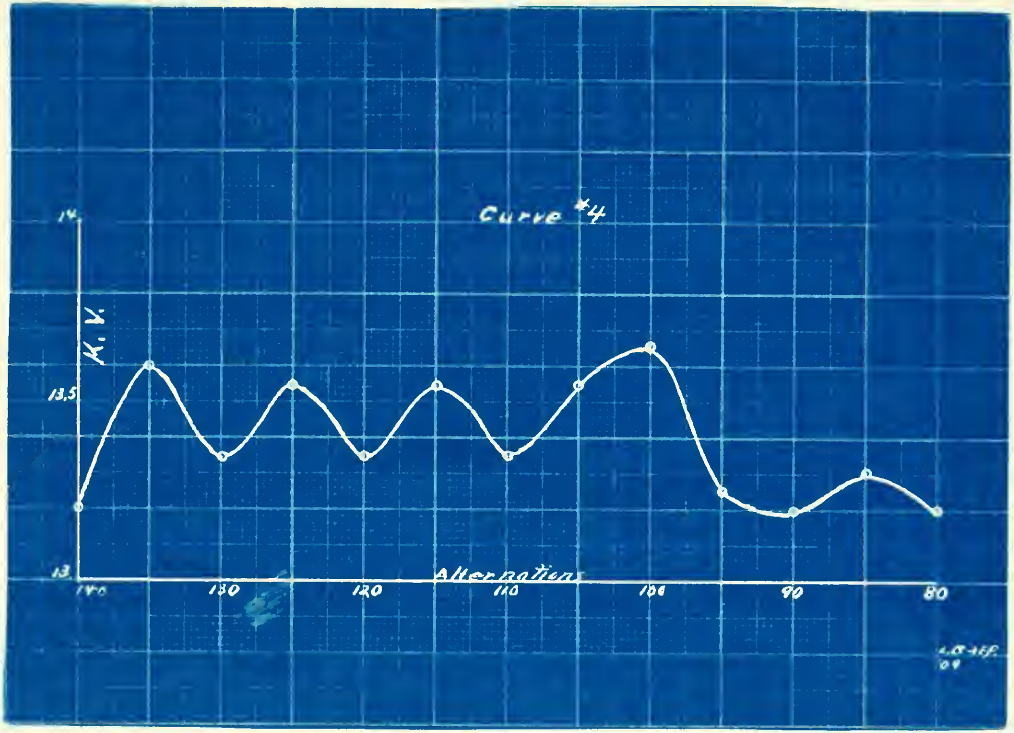
130
140
ALTERNATIONS
L.B.JEN
'09.


Curve #4
14.
13,5
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K. V.
Alternations
140
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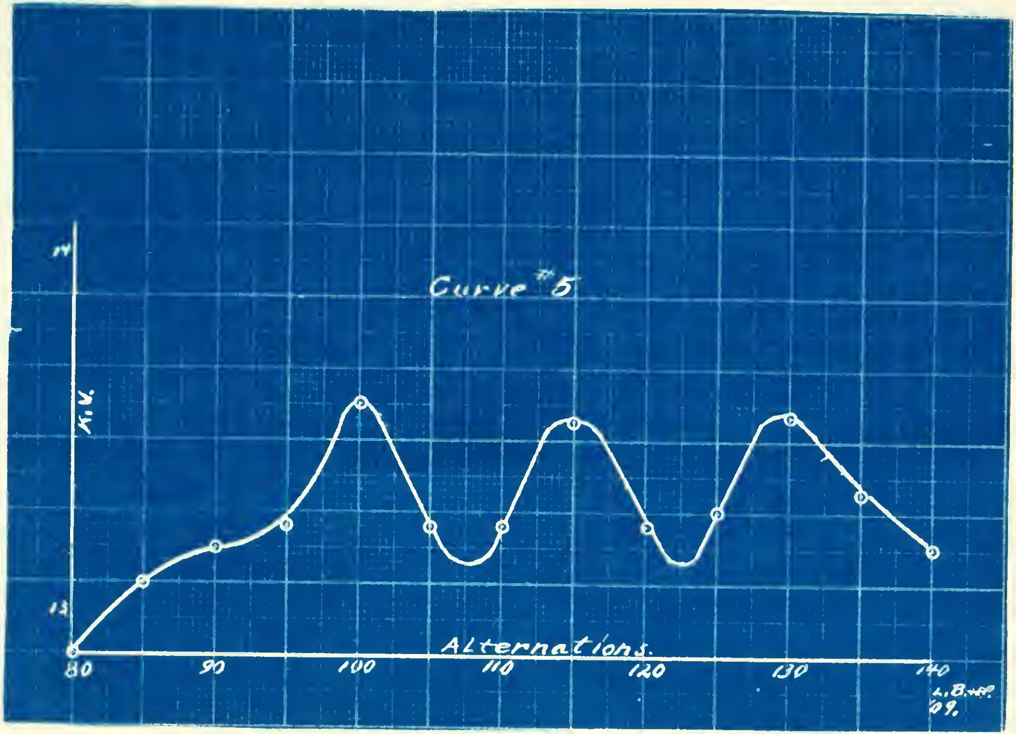

ARCHIVES
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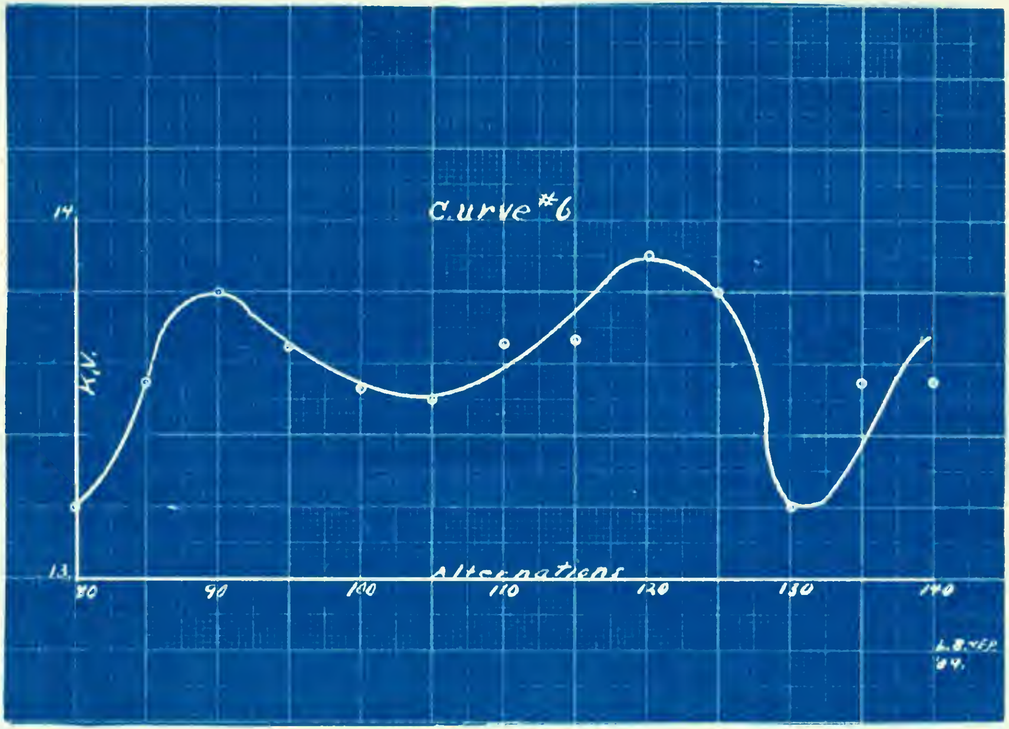
Curve #6
14
K.V.
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Alternations
L.B.MER.
'94.

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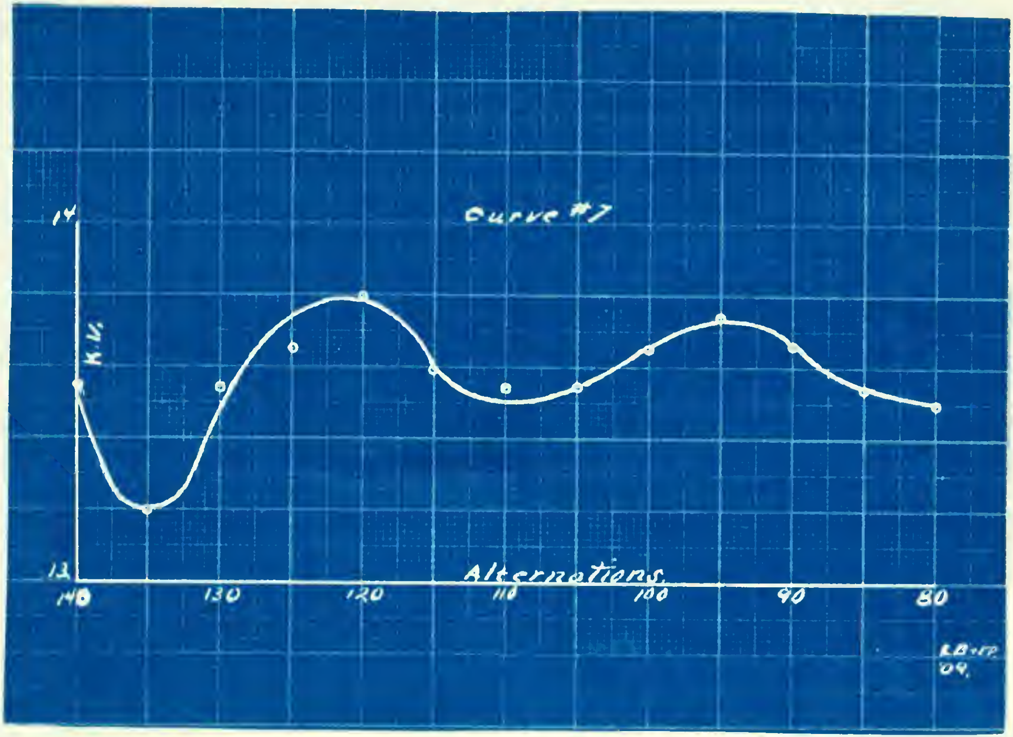
Curve #7
14
K.V.
13
Alternations.
140
130
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LB+FP
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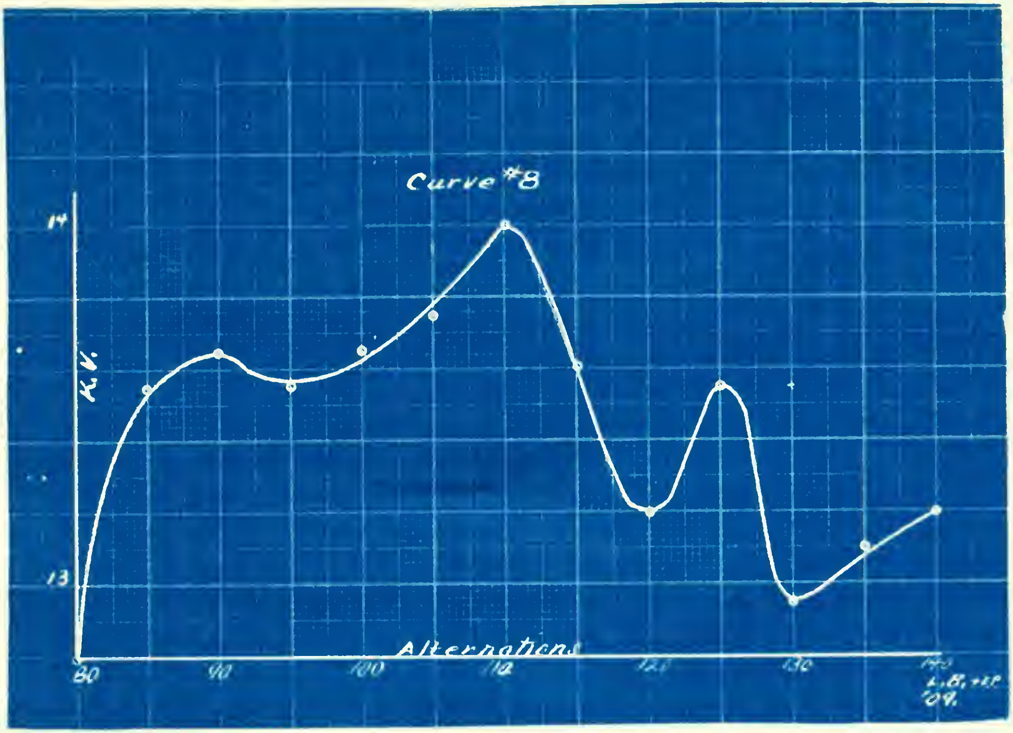
Curve #8
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K.V.
13
80
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120
130
140
Alternations
L.B., +E.P.
'09.

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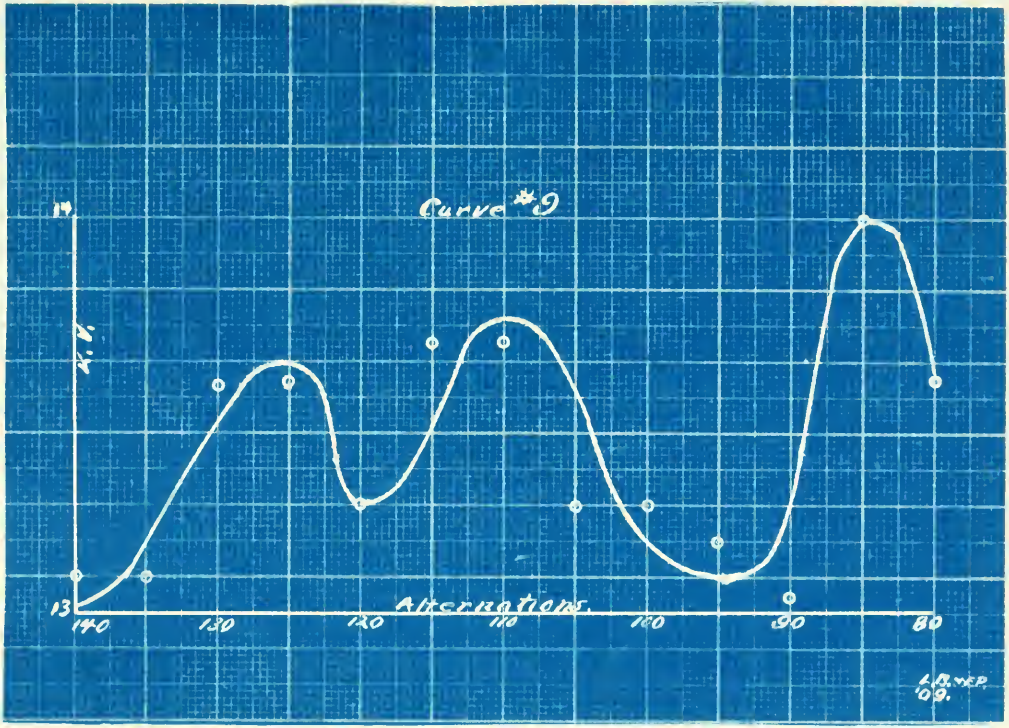
LIBRARY


Curve #9
14
K.V.
13
140
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Alternations.
L.B.&E.P.
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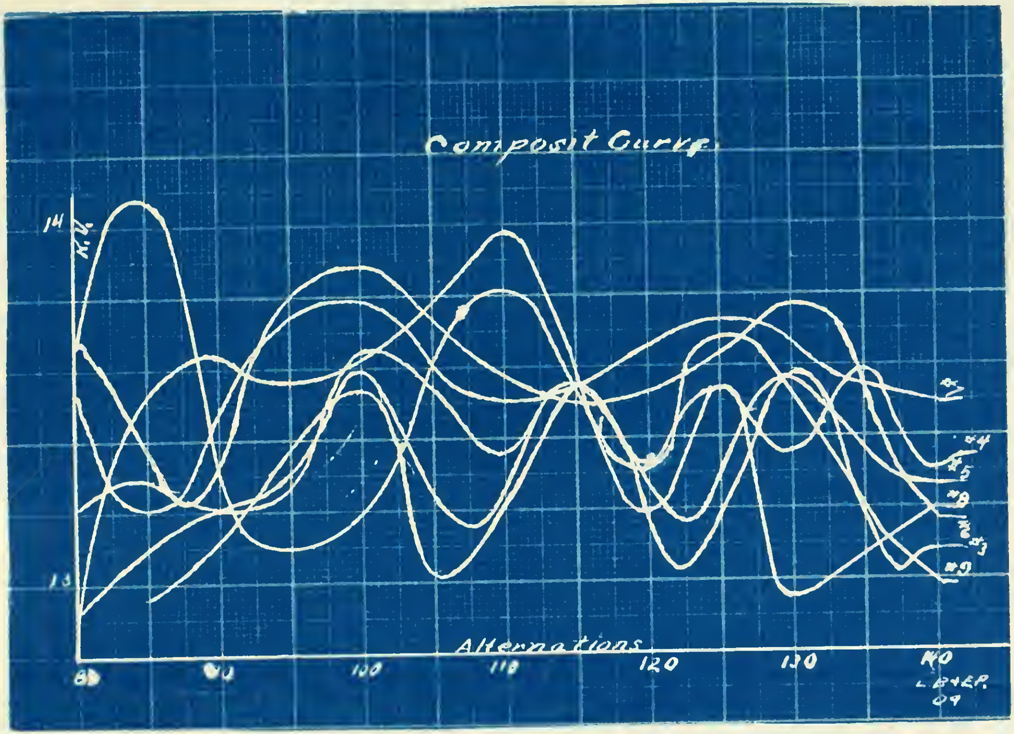Composit Curve
14
K.W.
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Alternations
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#7
#4
#5
#8
#6
#3
#9
L.B+E.P.
09

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PART VI.

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